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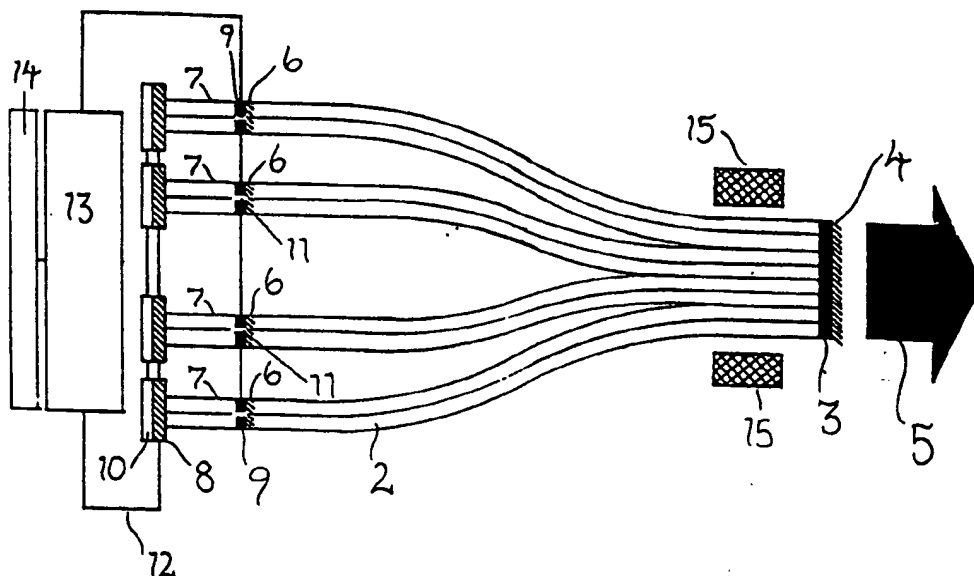
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(54) Title: CLOSE PACKED, END FACE, DIODE PUMPED, FIBRE LASER BUNDLE, PHASED-ARRAY LASER OS-
CILLATOR

(57) Abstract

This invention relates to a scaleable, phase-locked, fiber laser array laser oscillator system consisting of a bundle of single mode optical fiber lasers, which can be combined into tapes (16), one end of said bundle being compacted into a solid face (3) which acts as the output aperture of the invention whilst the other ends (6) of the fiber lasers, forming said bundle, are loosely b und either individually or in groups and connected to semiconductor light sources (7), or optical excitation sources with equivalent output characteristics, for the end pumping of said fiber lasers in such a manner that all can be excited simultaneously or in a selected sequence.

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CLOSE PACKED, END FACE, DIODE PUMPED, FIBRE LASER BUNDLE, PHASED-ARRAY LASER OSCILLATOR

FIELD OF THE INVENTION

This invention relates to a scaleable, phase-locked, fiber laser array laser oscillator system consisting of a bundle of single mode optical fiber lasers, which can be combined into tapes, one end of said bundle being compacted into a solid
5 face which acts as the output aperture of the invention whilst the other ends of the fiber lasers, forming said bundle, are loosely bound either individually or in groups and connected to semiconductor light sources, or optical excitation sources with equivalent output characteristics, for the end pumping of said fiber lasers in such a manner that all can be excited simultaneously or in a selected
10 sequence.

The phase-locking of the individual fiber lasers can be achieved using one of at least three phase-locking techniques, either individually or in combination, in the region of the compacted output face of the invention. Auxiliary optical excitation of the invention may be achieved using side pumping near the output
15 end using a fixed or movable diode array, or equivalent light source, emitting narrow band optical excitation light. The individual fiber laser oscillators of the invention may have a fixed or continuous variable fiber cladding thickness.

The invention has applications in the industrial, defence, medical communications, mass entertainment and the commercial fields.

20 PRIOR ART

Prior art, scaleable, coherently packed, coherently phase-locked array continuous path, end pumped fiber bundle lasers have either possessed two compacted ends or a single, common compacted end. Such compacted end,

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continuous path, bundled fiber oscillator lasers are difficult to end pump with arrays of diode lasers at high coupling efficiencies.

The present invention overcomes the defects of the prior art fiber bundle lasers in that one of the ends, the pumping end, is loosely bound and can be effectively coupled to well distributed, and hence, easily cooled arrays of laser diodes whether said diodes emit their optical outputs parallel to or perpendicular to the surface of the semiconductor chip on which they are mounted. The invention is particularly suited for the direct coupling of such semiconductor excitation sources to tapes of fibers from which it can be constructed.

10 BACKGROUND OF THE INVENTION

Starting in 1963, at the Royal Radar Establishment in the United Kingdom, I have pioneered the development of phase-locked arrays of optical fibers and optical fiber lasers. The first unclassified reference to this work appeared in "Applied Optics" USA July, 1979. My first US patent in this field was classified in 15 1984 and my first unclassified patent in the field was issued by the US Patent Office in July 1987 (US: 4,682,335). To date, the experimental fiber laser bundle arrays that I have assessed have been limited to 6 x 6 arrays due to the cost of end/side coupling techniques where the diode pump lasers are side coupled into the fiber laser near one of its ends with about 87% coupling efficiency. However, the cost of such optical couplers are high compared to the 20 cost of directly end coupling, well distributed diode arrays into the loosely bound ends of the fibers or tapes of the present invention.

However, experience has shown that up to 75% of the heat associated with diode pumped solid state lasers is deposited within the diode arrays themselves. It is, therefore, essential that the diode arrays are well cooled for their most efficient operation. Furthermore, it is better to cool individual, small arrays of diode pumps than large, single arrays. Bearing in mind that the fiber laser oscillators are independent of the laser diode pump as far as their lasing action is concerned and dependent on them for pump light only, there is no need for

phase-locked diode pump arrays, provided they can be efficiently and individually coupled to the fiber laser ends or to groups of said ends.

Experience has shown that the cost effectiveness of fiber bundle lasers are critically dependent on the number of optical components that are needed in
5 each individual fiber oscillator. The reason for this stems from the fact that between 10,000 and 1,000,000 fiber end transmitters form the output aperture of phased-array lasers depending on both the fiber core and the fiber cladding diameters. Even at the lower resolution of 10,000 "pixels" per square centimeter, the cost of expensive optical components such as lenses in coupling excitation
10 diodes to individual fibers soon becomes prohibitive so that the greatest possible simplicity becomes the order of the day.

Ideally, a diode pumped fiber bundle laser should consist only of optical fiber and laser diodes, this being the goal of the present invention. However, there are practical necessities such as power supplies, inter connecting leads,
15 optical couplers and laser mirrors which inevitably add to the total cost of the system. A particularly attractive feature of the present invention is the optional use of optical fibers of continuously variable cladding thickness from being comparable to the core thickness at the output end to being much greater than the core thickness at the pump end. This solution allows for the extremely fragile
20 output ends of the fibers to gain mutual strength by being compacted together whilst their relatively tough pump ends can be loosely bound without fear of breakage. In such a case, the thin-walled fibers forming the output end can cross-couple for phase-locking without the need for the more expensive lens arrays which have to rely on accurate hexagonal bundling of the fiber ends to ensure
25 low cost matching. However, for full colour presentation, three separate fiber laser oscillators have to form the basic unit and these have to be packed into an area about 20 microns in diameter for best effect. This requirement spaces the fibers corresponding to a given colour, be it blue, green or red, further apart than the five micron or so needed for effective cross-coupling, implying the need for a
30 lens array to effectively phase-lock the invention. If such lens arrays are used, there is no need for variable cladding diameters on the fibers because the lenses

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can accommodate phase locking requirements at somewhat increased core separation on the other hand it is a relatively simple process to pull a fiber bundle to provide the required variable cladding thickness along the bundle.

SUMMARY OF THE INVENTION

5 It is an object of this invention to generate a single, scaleable, laser beam via phase-locking the outputs of an array of fiber oscillators, using the minimum number of optical components.

Another object of the invention is to provide a compacted output end of fiber laser oscillator as the output end of the invention and to disperse the
10 unbounded fiber ends of the invention so as to distribute the heat generating diode pump sources as much as possible and to allow their segmentation to reduce the heating problems.

Another object of the invention is to connect arrays of diode lasers to tapes of fiber laser oscillators whose output ends are stacked together to form the
15 output aperture of the invention.

Yet another object of the invention is to provide means of using all types of diode pumps, optically coupled to the free ends of said fiber lasers forming the fiber laser bundle of the invention.

Another object of the invention is to provide means of switching the diode
20 pumps either simultaneously or sequentially or in groups so as to produce either a high definition laser beam image on the output face or to scan the laser output beam of the invention.

Yet another object of the invention is to form the fiber laser bundle of a three fiber group, one fiber laser emitting blue light, the other green light whilst the third
25 laser in the group emits red light.

Yet another object of the invention is to side excite the compacted output end region of the invention so as to bring it up to lasing threshold, then to activate the invention above threshold in individual fiber laser oscillators via their end pumping.

5 This invention allows for the generation of a powerful, scaleable, single, switchable laser beam via the phase-locking of a large number of smaller laser beams emitted by an array of laser fiber oscillators bundled together so that one end of the said bundle is compacted into the output aperture of the invention. The small diameter of the individual fibers forming the said bundle of laser
10 oscillators allows for effective cooling of the laser medium which is in the form of the fiber's glass core. Furthermore, the long length of fiber in each oscillator allows for heat dissipation over a relatively long length of up to several metres depending on the absorption length of the laser ion doped fiber core being used.

 The output aperture of the invention can be scaled to larger dimensions in
15 two ways. Firstly, this can be achieved by stacking the optical fibers together one at a time and ensuring that their optically polished and suitably mirrored output ends are positioned in the same plane, so as to form what is essentially an optically polished and fully mirrored output aperture. Secondly, a coherently packed array of optical fibers can be formed simply by winding the said laser fiber
20 onto a drum and cutting an appropriately thick layer of said fibers. Furthermore, by grouping the fibers together so that the groups can be phase-locked together, it is possible to scale the output aperture of the invention in terms of groups of fiber bundles rather than a single fiber bundle. In its simplest phase-locking configuration, the fiber laser oscillators of the invention have cladding
25 thicknesses which allow effective cross-coupling between the fibers. For example, in a fiber with a core diameter of 5 microns, the cladding thickness should be of the same order for effective "cross-talk" to exist between fibers. In more complex output face configurations, phase-locking can be achieved using arrays of micro lenses with each micro lens coupling into its respective fiber core
30 to the laser mirror. The overlapping of such arrays of micro laser beams ensures their phase-locking in the invention as a whole. The third phase-locking

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technique utilizes an etalon to reflect portions of each micro laser beam laterally so that portions of it can enter neighbouring fiber transmitters in a given area of the output aperture. When using micro lens arrays, there is no need to depend on the "cross-talk" through the thin cladding of the fibers so that cladding
5 thickness can be uniform along the fibers.

One form of the invention which is very attractive from the view point of flat screen television projection is that where the output aperture is surrounded, in the same plane, with allowance of the diode pumps and their power sources. This compact disc configuration of the invention can be wall mounted or mounted
10 in a relatively confined space relative to the diameter of the laser beam produced. By connecting the switchable diode pumps to operate in synchronism with a transmitted TV signal, a real time TV image can be generated on the flat output aperture of the invention and diffused by placing a suitable diffuser in front of it. Without such a diffuser, the generated laser image from the invention would
15 simply be projected in a highly collimated laser beam which would be eye hazardous, hence the need for the coherent to incoherent converter for safe viewing. However, when projected onto a screen, the present invention acts as a high intensity image projector.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

20 A better understanding of the invention will be gained from the following description taken in conjunction with the accompanying drawings. It is emphasised that the ensuing teachings are exemplary and not limiting of the scope of the invention.

In the drawings:

25 Figure 1 is a schematic layout of a preferred configuration of the invention in its simplest possible configuration. Fibers of continuously decreasing cladding thickness one compacted to form an output face with their mirrored, optically polished ends all in a single plane and their free ends, with maximum cladding

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thickness, each mirrored for 100% reflection at the lasing wavelength and for maximum transmission at the pump wavelength. The diode pump, emitting a laser beam of circular cross-section being directly coupled into the circularly cored, mirrored fiber end. Each of the said pump diodes are switchable so that
5 they can either all emit their outputs simultaneously or in a pre-determined pattern under computer control.

Figure 2 is a schematic layout of the invention made up of fiber tapes, each tape being excited by an array of laser diodes.

Figure 3 is a schematic layout of the invention in the format of a television
10 projector with the central transmitting aperture surrounded by the laser diode pumps forms a flat screen TV image generator and projector.

Figure 4 shows the manner in which arrays of pump diodes can be directly connected into the invention using fiber of constant cladding thickness with rectangular ends.

15 Figure 5 shows the manner in which the invention is phase-locked using a lens array/mirror combination and is excited via a similar system via the free fiber ends.

DETAILED DESCRIPTION OF THE INVENTION

In Figure 1, numeral 1 indicates the laser ion doped optical fiber core whilst
20 numeral 2 indicates the fiber cladding whose thickness decreases uniformly to the compacted mirrored output aperture of the invention indicated by numeral 3. Numeral 4 indicates the partially transmitting mirror attached to the optically polished laser fibers forming aperture 3. Numeral 5 indicates the single output beam of the invention formed from the phase-locking of the individual laser
25 beams emitted by the fiber ends forming aperture 3. Numeral 6 indicates the fully reflecting mirror on the optically polished rear end of the optical fibers which are unbound but connected directly to their respective diode laser pumps indicated

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by numeral 7. Diode pump 7 emits a laser pump beam of circular cross-section in a direction perpendicular to the surface of the chip, indicated by numeral 8 onto which it has been deposited complete with resonator mirrors and electrodes indicated by numeral 9 and 10, its output beam emerging via a circular hole indicated by numeral 11 in electrode 9.

In Figure 1, numeral 12 indicates the connecting leads to the diode power supply indicated by numeral 13, which in turn is switched by the computer controlled unit indicated by numeral 14. Numeral 15 indicates a side pump diode stack which can be used to excite the invention to its operating threshold so that the end pumps 7 can be most effective in switching the individual fiber lasers of the invention above their operating threshold at high switching rates.

In Figure 2, numeral 16 indicates a tape of single mode optical fibers whilst numeral 17 indicates the partially mirrored output operation of the invention composed of stacked layers of the fiber tapes 16. Numeral 18 indicates the optically polished free ends of the fiber tapes 16 with the fiber cores, indicated by numeral 19 arranged in a close packed, rectangular configuration which matches the rectangular format of the diode pump arrays indicated by numeral 20. Numeral 21 indicates the electrical leads connecting the diode arrays 20 to their power supply indicated by numeral 22.

In Figure 3, numeral 23 indicates a single fiber tape of the invention with fiber ends of rectangular cross-section whilst numeral 24 indicates a fiber core of circular cross-section. Numeral 25 indicates a diode laser pump array with its emission beam of rectangular configuration as indicated by numeral 26, which matches the rectangular array of fiber cores 24. Numeral 27 indicates the electrical leads connecting the diode array 25 to its power supply (not shown).

In Figure 4, numeral 28 indicates a micro lens array/partially transmitting mirror combination. Numeral 29 indicates the micro lens array whilst numeral 30 indicates the partially transmitting mirror. Numeral 31 indicates a micro lens which matches the output of laser diode pump 32 to the mirrored fiber core

indicated by numeral 33.

In Figure 5, numeral 34 indicates the output aperture of the invention in the format of a television screen. Numeral 35 indicates the diffusion screen whilst numeral 36 indicates the output. Numeral 37 indicates the diode pumps of the invention whilst numeral 38 indicates their power supplies. Numeral 39 indicates the computer used to switch the invention into a television format.

The invention has applications in the defence, industrial, medical, mass entertainment and the commercial field.

Modifications may be made within the above described subject matter without departing from the spirit and scope of the invention.

I claim,

1. A scaleable phase-locked, laser fiber bundle oscillator system consisting of individual fibers whose cladding has variable thickness surrounding a constant diameter, single mode core, such that those optically polished fiber ends with
5 minimum cladding thickness are compacted together to form the output aperture of the invention onto which is attached a partially transmitting mirror at the output wavelength, the other, optically polished ends of the said fibers possess the larger cladding thickness are left loose and mirrored for total reflection at the laser wavelength and maximum transmission at the pump wavelength, the
10 individual diode pumps being in direct contact with said fiber ends producing a direct coupling between the circular cross-section of said diode pumps and the circular cross-section of the fiber core. The invention having auxiliary side pumping diode stacks surrounding its output end to aid its excitation, said side diode pumps being capable of being switched in whole or in part, or moved
15 relative to said fiber bundle to minimise the localised over-heating of said fibers.
2. A fiber bundle laser oscillator system as claimed in Claim 1 where its phase-locking is aided by optical transmission through the thinly clad ends of the fibers forming the output aperture of said system.
3. A fiber bundle laser oscillator system as claimed in Claim 1 where its phase-
20 locking is aided by a portion of the laser light emitted by each fiber end forming the output aperture being reflected off the partially transmitted output mirror so as to enter neighbouring fibers in said aperture.
4. A laser system as claimed in Claim 1 where the circular cross-section and mirrored fiber cones are directly matched to the output beams of circular cross-
25 section beams generated in laser diodes which emit their output in a direction perpendicular to the surface of the substrate onto which they are mounted.
5. A scaleable, phase-locked, laser fiber bundle oscillator system consisting of individual fibers whose cladding has a constant thickness surrounding a constant

diameter single mode core, such that one set of optically polished fiber ends are compacted together to form the output aperture of the invention onto which is attached on micro lens array/partially transmitting mirror combination, which provides an aid for phase-locking the outputs of the individual fiber laser ends
5 from the output aperture by allowing portions of the emissions from a given fiber end to enter its neighbouring fibers end forming the said aperture.

6. A system as claimed in Claim 5, where the pump diodes are matched to the free, mirrored fiber ends via direct contact of the circular cross-section fiber core and the circular cross-section emission pump beam emission for the said laser
10 diodes.

7. Systems as claimed in Claims 1 and 4, where the fibers are combined into a series of tapes, whose free ends are etched so as to produce fiber ends of rectangular cross-section, which being in a fiber tape provide a close patterned row of cores which are directly matched to the pump diode arrays, where the
15 diode emissions, in the form of laser beams of rectangular cross-section, are emitted in a direction parallel to the substrate onto which they are mounted.

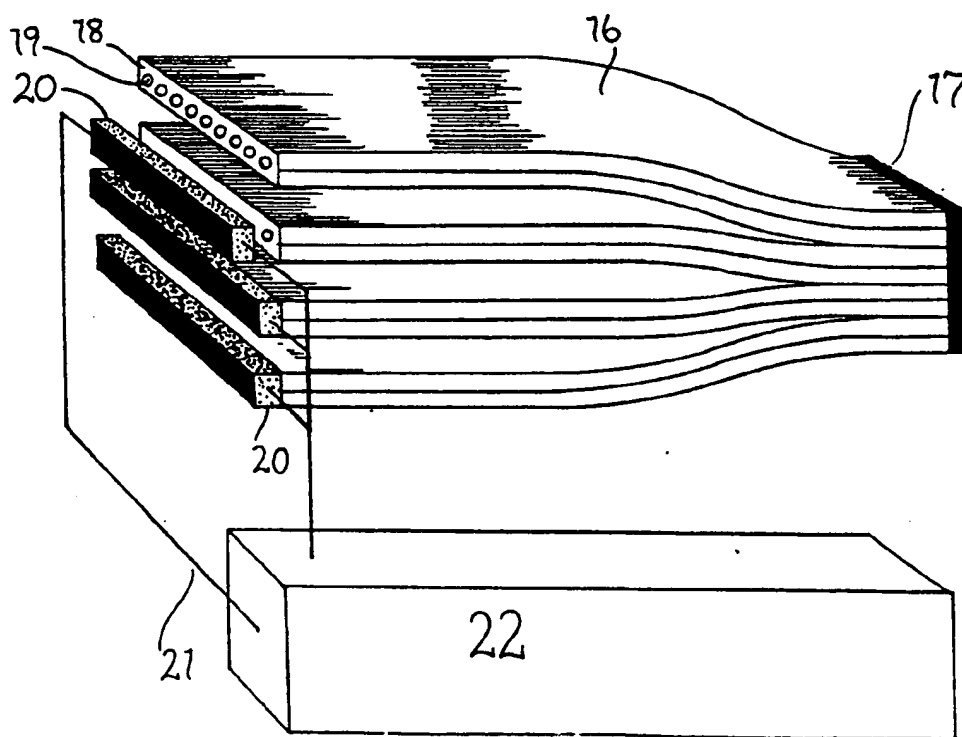
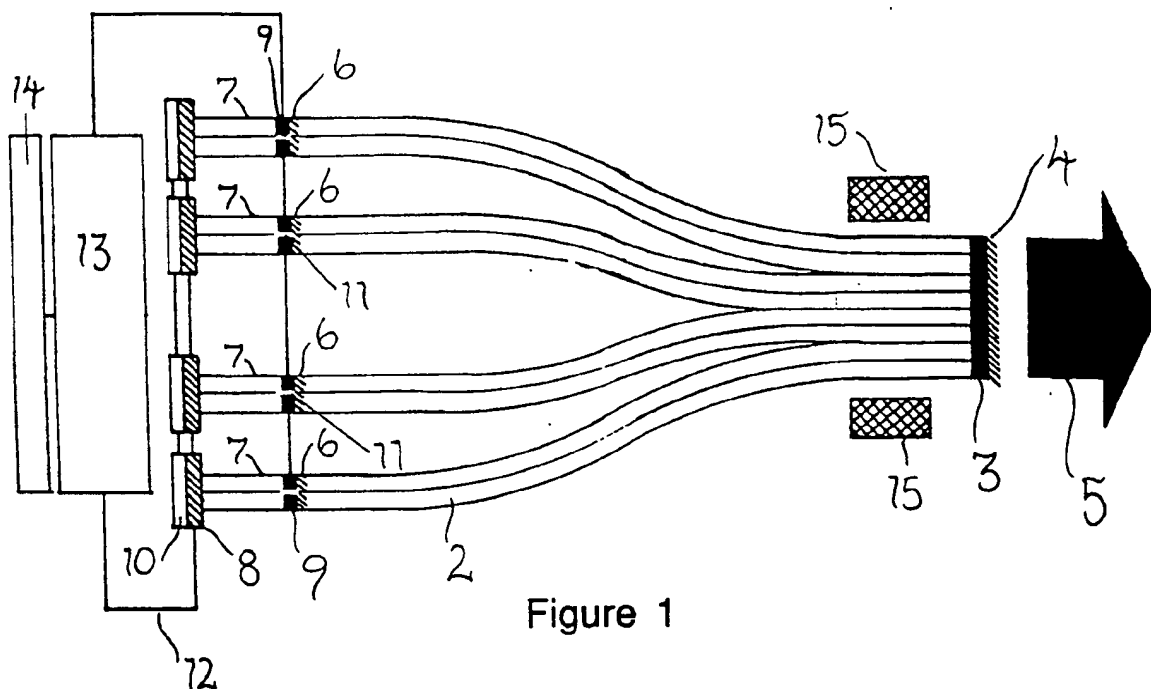
8. A system as claimed in Claims 1 and 4 where the compacted output aperture of the invention is in the same plane as both the diode pumps, their power supplies and control computers, forming a compact television system
20 in which high definition images are generated by the appropriate switching of the individual fiber lasers forming said bundle, with a diffusing screen being positioning in front of the output aperture of the invention to transform the laser beams into eye safe light images when the invention acts as a television.

9. A system as claimed in Claim 8 where each single fiber of said fiber bundle
25 is replaced with a set of three fibers, one transmitting blue, one green and the other red laser light.

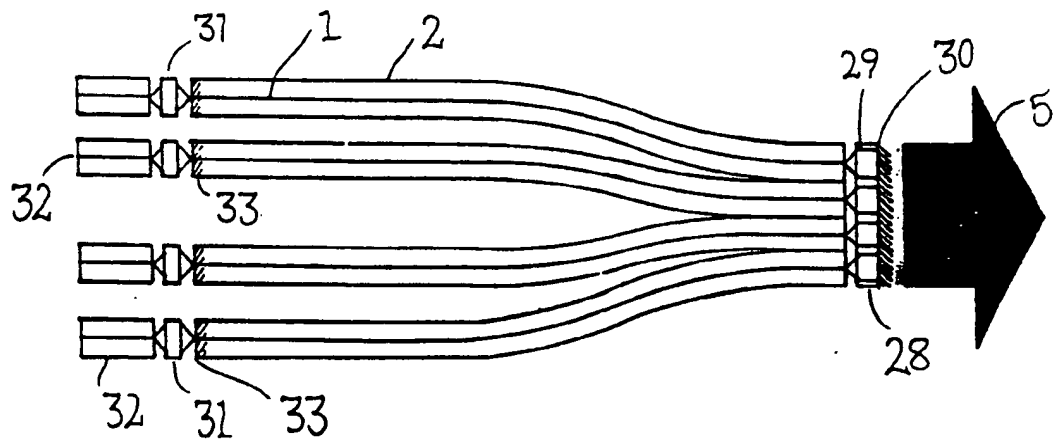
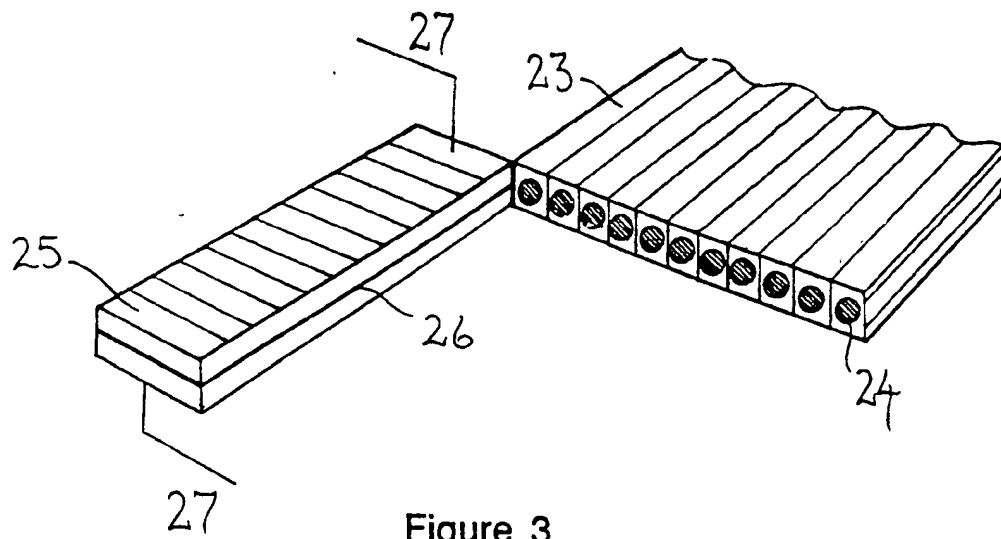
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10. A system as claimed in Claim 8 where the said diffusing safety screen is composed of colour generating dyes which are selectively active in the blue, green and red via interaction with the appropriately emitted laser beams of the invention.

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SUBSTITUTE SHEET

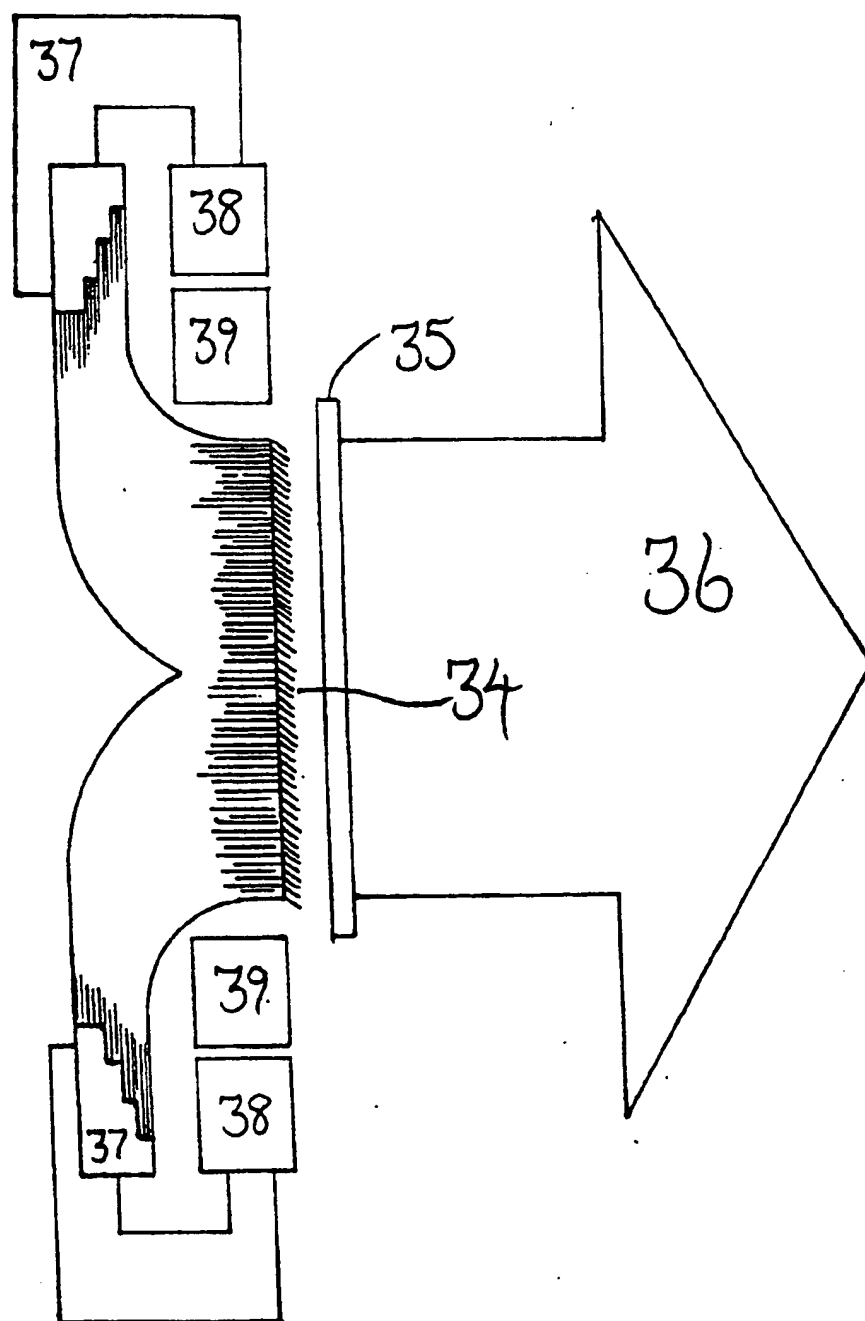


Figure 5

INTERNATIONAL SEARCH REPORT

International Application No. PCT/AU 90/00151

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) 6

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.⁵ H01S 3/07, 3/08, 3/094, G02B 6/32

II. FIELDS SEARCHED

Minimum Documentation Searched 7

Classification System | Classification Symbols

IPC | H01S 3/07, 3/08

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched 8

AU : IPC as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT 9

Category*	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages 12	Relevant to Claim No 13
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A	AU,A, 53514/79 (HUGHES et al) 26 June 1980 (26.06.80)	
A	AU,B, 38742/85 (583029) (HUGHES TECHNOLOGY PTY LTD) 22 August 1985 (22.08.85)	
A	US,A, 4479224 (REDIKER) 23 October 1984 (23.10.84)	
A	US,A, 3471215 (SNITZER) 7 October 1969 (07.10.69)	
A	EP,A, 97250 (I.B.M.) 4 January 1984 (04.01.84)	
A,P	WO,A, 89/12923 (AUSTRALASIAN LASERS PTY LTD) 28 December 1989 (28.12.89)	

- * Special categories of cited documents: 10 "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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- "&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search 22 June 1990 (22.06.90)	Date of Mailing of this International Search Report 10 July 1990
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International Searching Authority

Signature of Authorized Officer

Australian Patent Office

W.J. MAJOR

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON
INTERNATIONAL APPLICATION NO. PCT/AU 90/00151

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document
Cited in Search
Report

Patent Family Members

AU 53514/79

GB 2039381

AU 38742/85

GB 2154364

US 4682335

US 3471215

DE 1539653

GB 1155372

EP 97250

DE 3365603

JP 59007360

US 4516832

WO 8912923

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END OF ANNEX